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Investigation of the process and performance of a molding wood substitute packaging material

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A molded wood substitute packaging material was obtained through the breaking, molding and drying of the wood processing residues. The samples of different wood substitute packaging material were prepared through the orthogonal design method and the influence of different process parameters on wood substitute material's physical and mechanical properties was analyzed via a range of analytic techniques. Wood substitute packaging material with better properties can be afforded via the process of hot-pressing for 10min at the conditions of 120～125℃ under 10MPa pressure with sizing amount of 20%. The resultant wood residues packaging products can meet the requirements of national standard (GB/T 4897-92D) and also the standards of green packaging materials.

Keywords: wood substitute packaging material, mold pressing, process parameters, physical and mechanical properties

INTRODUCTION

With a worldwide shortage of forest resources, global supply of wood raw material is becoming increasingly tense [1]. As in China, the forest resources are scarce and the supply and demand of timber is imbalanced [2]. At present, the annual timber gap is about 7×107m^3. Meanwhile, the full use of processing residua and waste wood from the consumption of industries and human life will greatly ease the supply and demand of China's timber [3].

The poplar plantation has some processing shortages, such as uneven distribution, low-density, the prone to shrinkage deformation and veneer peeling raising [4]. All these bring a lot of difficulties to development and utilization [5]. However, high moisture content and soft material simplify the manufacturing board technology and lower the production cost [6]. For the time being, poplar material is one of the main raw materials of the wood-based panel production [7].

This paper aims at further using orthogonal test method to analyze the influences of hot - pressing temperature, hot-pressing time and hot-pressing pressure sizing amount. on the physical and mechanical properties followed by formulation and optimization of its molding process parameters [8].

EXPERIMENTAL

Materials

Poplar fiber: Processing fast-growing poplar's branches into cells with the diameter of 3～4cm by chipping machine. Dry and ground them after cooking and softening, then make them into poplar fiber with moisture content of 15%～20%.

Melamine modified urea - formaldehyde resin adhesive as the resource. Its solid content is 50～55%, viscosity is (20℃) 26～30cps and curing time is 90～120s.

The pretreatment agent for the poplar fiber is NaOH solution, the mass fraction of 1.5% according to the mass ratio of 1: 100 between NaOH (AR) and poplar. The solution must be used right after it is ready.

Curing agent: choose NH4Cl (AR) as the curing agent.

Instrument

Three-point bending experiment was conducted on RXPlus Universal electronic testing machine made in Lloyd company and the accuracy is 0.5%, span is 100mm. The force was applied at the rate of 60mm/min. Experiments were conducted in packaging products quality supervision and inspection center of China.

Methods

Preparation of wood residues packaging products

According to related documents, there are several factors have a great impact on plates: sizing

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amount, hot - pressing temperature, hot-pressing time and hot-pressing pressure. This study adopts Orthogonal Test Method and chooses L9(34) to research the above four factors' influence on physical and mechanical properties. According to early study and practice, select three levels of each factor [9] (see Table 1).

Table 1. Orthogonal Factors Table.

Level	A Sizing amount(%)	B Temperature (˚C)	C Time (min)	D Pressure (MPa）
1	10	100~105	5	5
2	15	120~125	10	8
3	20	140~145	15	10

Weighing and paving fibers into mold cavity in size of 250mm×50mm×14mm and then forming a single slab of particle board with density of 0.75g/cm3. After about 30～60s' manual preloading, press the slab without too much pressure. Discharge the water vapor inside to prevent the packaging products from bumps and stratification [10].

The prepared key issues of the wood residues packaging products

The high rate of residues is due to the serious phenomenon of stratification and bumps. There are two solutions: First, the hot-pressing temperature cannot be higher than 180˚C. And the time should be at least 8.5min; second, after the clamping of the upper and lower mold, the pressure is adjusted to maximum of the testing design for about 60s. Then the pressure reduced to zero quickly and split up mold, making the rapid discharge of water inside the mold then adjust the pressure to the designed value.

Physical and mechanical property testing

The physical and mechanical property testing conducted in accordance with the GB/T 17657-1999 [11]. The testing includes MOR, MOE, IB, TS, density and so on.

RESULTS AND DISCUSSION

The physical and mechanical property testing of wood substitute packaging materials conducted in accordance with the GB/T 17657-1999. The testing includes MOR, MOE, IB, TS, density and so on. The testing results are shown in Table 2.

Factors analysis to packaging products' MOR

MOR is the determinants of the maximum capacity packaging products resisting bending forces without being destroyed [12]. According to the orthogonal testing results, the range result of the hot-pressing parameters' impact on the MOR is shown in Table 3.

Influence analysis of hot-pressing temperature on MOR

In hot-pressing parameters, temperature has a great impact on mechanical property [13]. First, when the moisture content is certain, the fiber's plasticity can be significantly improved by raising temperature. Then it will be easier to control the plate's thickness and density. Second, raising temperature can make adhesive cure rapidly, and shorten hot-pressing time. Meanwhile, it can increases the fluidity of the adhesive so that the distribution will be more evenly. When temperature is too high, the outer glue is already going to solidify

Table 3. Analysis of the range of MOR

		Temperature (˚C)	Time (min)	Pressure (MPa)	Sizing amount (%)
MOR (MPa)	1	51.3	55.1	46.8	38.7
	2	55.7	58.7	53.8	73.9
	3	57.1	50.3	63.5	51.5
	R	5.8	8.4	16.7	35.2

Table 2. Orthogonal Test Results

Testing number	Factor				Physical and mechanical property			
	Sizing amount(%)	Temperature (˚C)	Time (min)	Pressure (MPa）	MOR (MPa)	IB (MPa)	TS (%)	Density (g/cm3)
1	10	100~105	5	5	11.2	1.43	7.3	0.682
2	10	120~125	10	8	12.8	1.51	7.1	0.689
3	10	140~145	15	10	14.7	1.57	6.8	0.758
4	15	100~105	10	10	29.7	1.72	4.2	0.681
5	15	120~125	15	5	19.4	1.64	5.6	0.723
6	15	140~145	5	8	24.8	1.83	4.8	0.902
7	20	100~105	15	8	16.2	1.69	5.4	0.777
8	20	120~125	5	10	19.1	1.74	5.3	0.725
9	20	140~145	10	5	16.2	1.68	6.9	0.961

before reaching the preset pressure value, so this layer's strength will be low and high temperature will make fiber's adhesive degrade, reducing its strength [14]. On the contrary, when the temperature is too low, the lignin inside the poplar fiber cannot be fully melted and cannot play the role of gluing. So low temperature is difficult to improve packaging products' MOR [15].

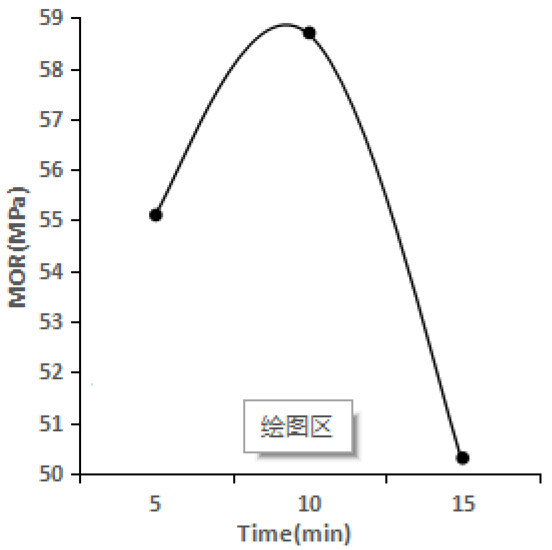

Fig. 1. Hot-pressing temperature's influence on MOR

The hot-pressing temperature's influence on MOR is shown in Fig. 1. We can know from the Fig. 1: as the temperature rises, the MOR increases and the change of MOR is larger in the range of 100～125℃. But when in 125～145℃, the change of MOR become relatively slow. It indicates that too high temperature will reduce packaging products' MOR. From the comprehensive consideration of energy saving and packaging products' MOR, the best temperature for hot - pressing is 120～125℃.

Influence analysis of hot-pressing time on MOR

The overall moisture content of slab is over 15%～20%, that will produce a large amount of water vapor, and leads to the phenomenon of bumps and stratification in the surface. In addition, high moisture content will extend the curing time of adhesive. In order to solve it, the time should be extended properly. However, extending the pressing time directly influences the production cycle. The influence of pressing time on MOR is shown in Fig. 2.

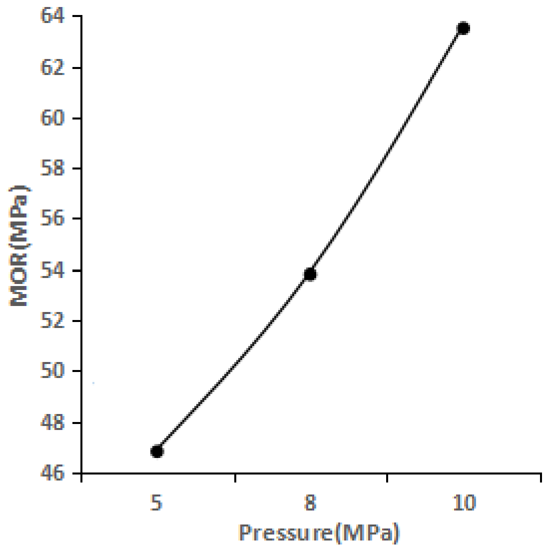

Fig. 2. Hot-pressing time's influence on MOR

From Fig. 2, we can know that: within a certain range, the MOR will increase along with the extension of time. But when higher than the range, the MOR will reduce. At the same temperature, the longer the time is, the more obvious the coking phenomenon and the degradation and catalysis of the adhesive, leading to the decrease of the MOR. When the pressing time is short, the slab inside will not reach the required temperature and the lignin will not been fully fused, which will cause the decrease of the MOR. From the comprehensive consideration of energy saving and the MOR, the most proper time is 10min.

Influence analysis of hot-pressing pressure on MOR

During the process of hot-pressing, exerting some pressure is mainly in order to discharge part of the air inside the slab, so that the poplar fiber can be bonded together in close contact to achieve higher bonding strength. Increasing the pressing pressure at the beginning can increase the core layer's density and gradient and improve its MOR. And also can narrow the gap between poplar fibers and increase the gluing area, which is good for the gluing of the poplar fiber. Nevertheless, too much pressure will crush the packaging products and reduce MOR.

The influence of hot-pressing pressure on MOR is shown in Fig. 3. We can know from the Fig. 3: as the pressure increases, the packaging products' MOR is also on the rise. Mainly because the increasing pressure makes the gap between poplar fiber smaller and the gluing area increases, thereby increasing the MOR. Taking all factors into consideration, the best pressure during the process of hot - pressing is 10MPa.

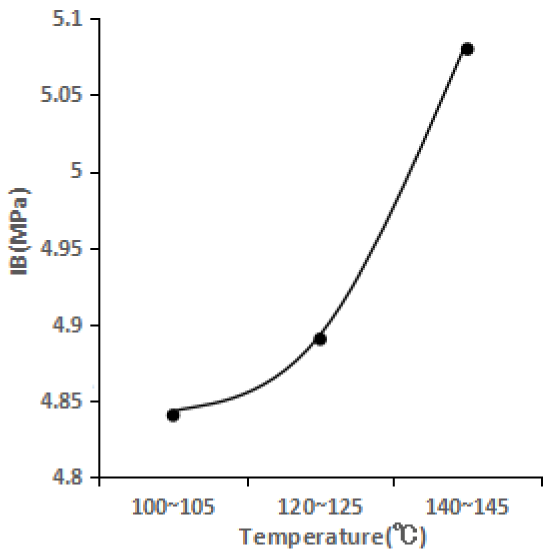

Fig. 3. Hot-pressing pressure's influence on MOR

Based on the analysis of various factors on MOR, we can know that the value of range in size order is sizing amount, hot-pressing pressure, hot-pressing time and hot-pressing temperature. Therefore, the best formula for MOR is when the hot-pressing temperature is 120～125°C, hot-pressing time is 10min, hot-pressing pressure is 10MPa and the sizing amount is 20%.

Factors analysis to packaging products' IB

IB means the bonding strength between the poplar fibers inside the packaging products. The larger IB is, the greater ability the packaging products possess to resist the bending due to the changing temperature. The range results the hot - pressing parameters have on the packaging products' IB during the pressing process is shown in Table 4.

Table 4. Analysis of the range of IB

		Temperature(˚C)	Time(min)	Pressure(MPa)	Sizing amount(%)
	1	4.84	4.90	4.75	4.51
IB	2	4.89	4.99	5.13	5.19
(MPa)	3	5.08	5.01	5.03	5.11
	R	0.24	0.11	0.38	0.68

Influence analysis of hot-pressing temperature on IB

The IB is mainly determined by two factors: one is the level of pressing temperature and the other is the binding capacity between poplar fibers. Among them, too high pressing temperature will make the surface solidify rapidly, even have the coking phenomenon. But the temperature inside does not increase rapidly, the filled adhesive does not play a role. Meanwhile, high temperature may make the adhesive itself contains degrade and the IB decrease. When the pressing temperature is too low, the pressing cycle will be extended. The temperature inside cannot reach the requirement for the purpose of material gluing and lead to the decrease of IB.

The influence of hot-pressing temperature on IB is shown in Fig. 4. We can know from the Fig. 4: as the pressing temperature increases, the IB is also on the rise. Mainly because the increase of pressing temperature make the temperature inside the slab increase and the adhesive the poplar fiber itself contains produce gluing effect, thereby increasing the IB. But the bonding strength in the surface will decrease. Because of the high temperature, the phenomenon of coking and adhesive degradation is appeared in the surface. Therefore, the best hot-pressing temperature is 120～125°C.

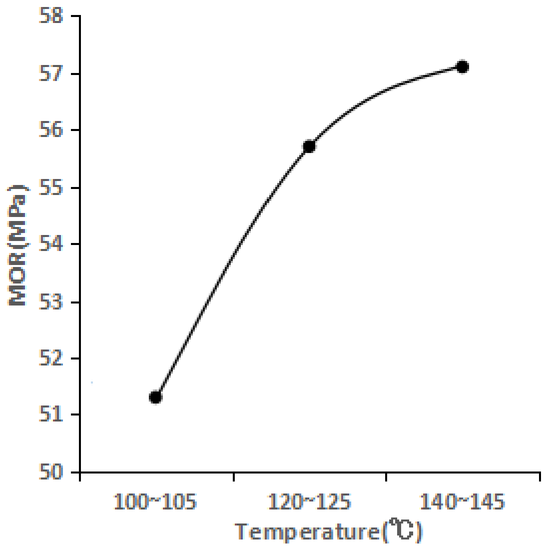

Fig. 4. Hot-pressing temperature's influence on IB

Analysis of the influence of hot-pressing time on IB

The influence of hot-pressing time on IB is shown in Figure 5. We can know from the Figure 5: the influence of hot - pressing time is relatively small. In a short time, pressing temperature cannot sufficiently spread into the inside of the slab so that it won't have a good bonding and combination between poplar fibers. Therefore, the IB is relatively low in 5minutes. But the strength of IB between 10min and 15min has no big difference. For IB of packaging products, the best time for hot - pressing time is 10min.

Influence analysis of hot-pressing pressure on IB

During the process of hot-pressing, the pressure is of great significance to control the resilience of the slab. Larger hot-pressing pressure can make the density of packaging products greater and strengthen the bonding and combination between the poplar fibers inside the packaging products. But too much pressure will make the slab crushed and increase the MOR and IB. Therefore, a reasonable choice of hot-pressing pressure is important. The influence of hot-pressing pressure on IB is shown in Figure 6. We can know from the Fig. 6: within a certain range, as the pressure increases, the packaging product' IB will increase. But if the pressure is too large, the IB will decrease. So for IB, the optimal hot-pressing pressure is 8MPa during the process of hot-pressing.

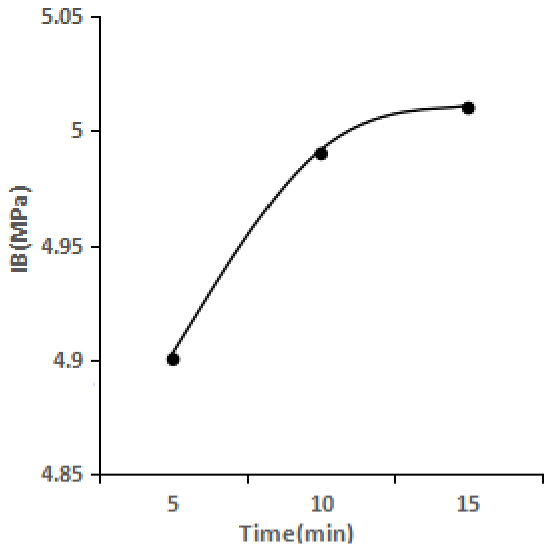

Fig. 5. Hot-pressing time's influence on IB

Influence analysis of hot-pressing pressure on IB

During the hot-pressing process, the pressure is of great significance to control the resilience of the slab. Larger hot-pressing pressure can make the density of packaging products greater and strengthen the bonding and combination between the poplar fibers inside the packaging products. But too much pressure will make the slab crushed and increase the MOR and IB. Therefore, a reasonable choice of hot-pressing pressure is important. The influence of hot-pressing pressure on IB is shown in Fig. 6. We can know from the Fig. 6: within a certain range, as the pressure increases, the packaging product' IB will increase. But if the pressure is too large, the IB will decrease. For IB, the optimal hot-pressing pressure is 8MPa during hot - pressing process of. Based on the analysis of various factors on IB, we can know that the order is sizing amount, hot-pressing temperature, hot-pressing pressure and hot - pressing time. Sizing amount has the greatest impact on IB while the hot-pressing time is the least. Therefore, the best formula for IB is that the hot-pressing temperature is 120～125℃, hot-pressing time is 10min, hot-pressing pressure is 8MPa and sizing amount is 20%.

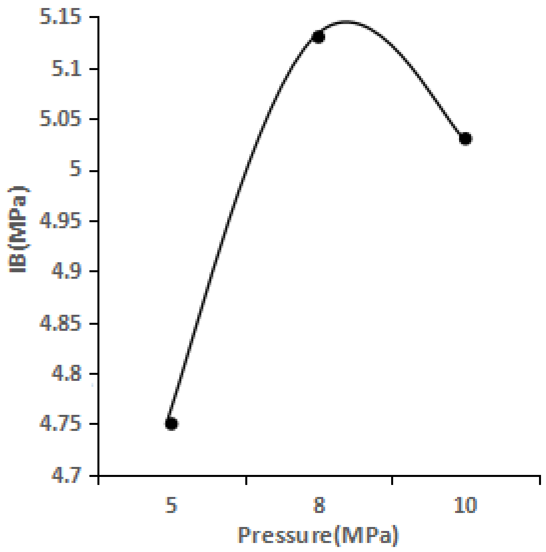

Fig. 6. Hot-pressing pressure's influence on IB

Factors analysis to packaging products' TS

TS means the ratio of the packaging products' thickness before absorbing and after absorbing in a certain time. The larger TS is, the quicker the thickness decreases after the absorbing and the greater the degree of bending deformation. The range results the hot-pressing parameters have influence on the TS during the pressing process is shown in Table 5.

Table 5. Analysis of the range of TS.

		Temperature (˚C)	Time (min)	Pressure (MPa)	Sizing amount(%)
TS (%)	1	18.0	19.3	17.3	20.2
	2	16.9	18.1	19.8	15.6
	3	18.5	17.4	16.3	17.6
	R	1.6	1.9	3.5	4.6

Influence analysis of hot-pressing temperature on TS

Too high temperature will lead to the phenomenon of coking and increase the absorbing capacity, thereby increasing the TS. Proper pressing temperature will increase the TS by forming the pre-cured layer in the surface. When the hot-pressing temperature is low, the surface of packaging products is not fully cured and the poplar fiber inside the slab does not bond and combine greatly. It leads to the larger thickness and then the absorbing capacity increases and the TS increases. The influence of hot-pressing temperature on TS is shown in Fig. 7. We can know from the Fig. 7: within a certain range of temperature, the thickness decreases. But when the pressing temperature is too high, the TS increases rapidly. Taking all these factors, for TS, the optimal temperature in the process of hot pressing is 120 ～ 125̊C.

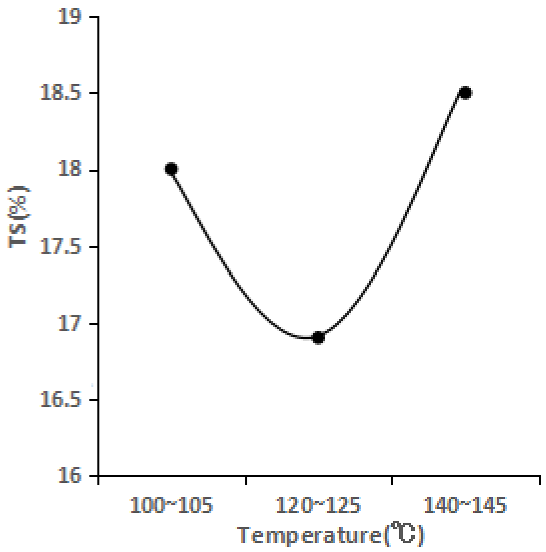

Fig. 7. Hot-pressing temperature's influence on TS

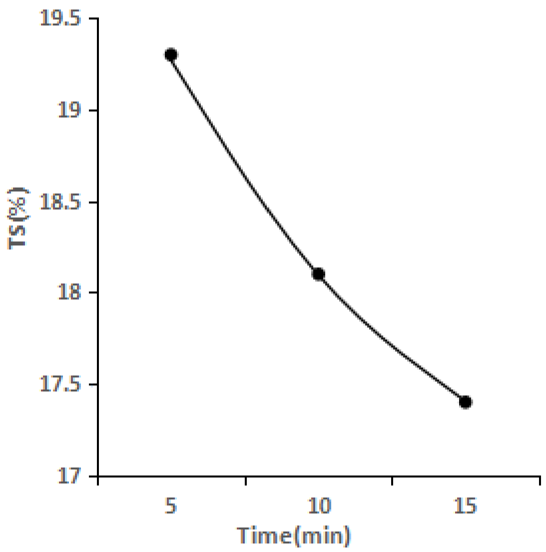

Fig. 8. Hot-pressing time's influence on TS

Influence analysis of hot - pressing time on TS

With the extension of pressing time, the adhesive is fully cured. It will be very hard for moisture to permeate into the fiber, so the TS of packaging products decreases. Therefore, during the process of hot pressing, packaging products which require low TS should extend the pressing time properly. The influence of pressing time on TS is shown in Fig. 8. We can know from the Fig. 8: with the extension of pressing time, packaging products' TS decreases rapidly. Taking all these factors, for TS, the optimal time for hot pressing is 15min.

Influence analysis of hot-pressing pressure on TS

Hot-pressing pressure has a great impact on TS. Certain pressure can make the fibers more closely combine and increase the liquidity of adhesive. The influence of hot-pressing pressure on TS is shown in Fig. 9. We can know from the Fig. 9: with the increase of hot-pressing pressure, packaging products' TS increases first, and then decreases. As pressure increases, the slab is crushed and the combination between the poplar fibers become more closely, which make the TS decrease. Taking all factors, for TS, the optimal pressure for hot pressing during the process of pressing is 10MPa.

Based on the analysis of various factors on packaging products' TS, we can know that the value of range in size order is sizing amount, hot-pressing temperature, hot-pressing time and hot - pressing temperature. That is, sizing amount has the greatest impact on IB while the hot-pressing temperature is the least. Therefore, the best formula for TS is when the hot-pressing temperature is 120～125℃, hot-pressing time is 15min, hot-pressing pressure is 10MPa and the sizing amount is 20%.

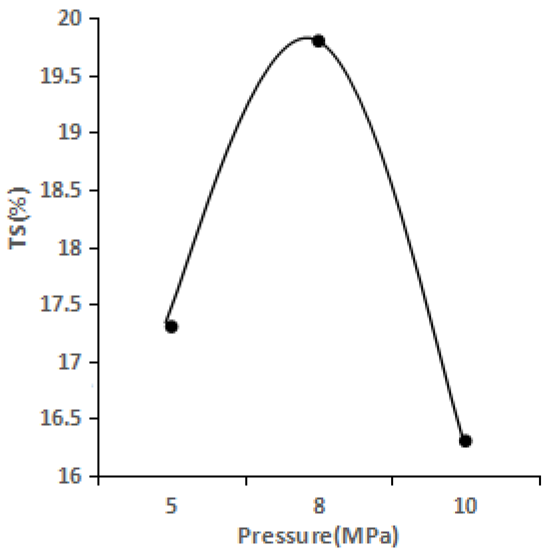

Fig. 9. Hot-pressing pressure's influence on TS

CONCLUSION

Based on the analysis of the physical and mechanical properties of packaging products and combining some features and requirements in the process of hot-pressing, we can draw a conclusion of a better molding process parameters, which are the hot-pressing temperature at 120～125℃, the hot-pressing time with 10min, the hot-pressing pressure of 10MPa and the sizing amount of 20%.

During the process of hot-pressing, the temperature, the time and the pressure are closely related and mutually restrained. Properly increasing temperature or pressure can shorten the pressing time and save energy.

The physical and mechanical properties of packaging products made from the above hot - pressing process parameters meet the requirement of national standard (GB/T 4897-92D) [16].

In order to reduce the phenomenon of stratification and bumps, the moisture content of poplar fiber should be controlled between 15%～20% during the hot-pressing. The process takes the way of secondary pressure and the slab should be preloaded before the real hot-pressing.

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